Purdue University
Purdue e-Pubs

International Compressor Engineering Conference | School of Mechanical Engineering

1976

Use of Computer Graphics to Visualize Compressor Simulations

M. Bailey

D. Strader

D. C. Anderson

W. Soedel

USE OF COMPUTER GRAPHICS TO VISUALIZE COMPRESSOR SIMULATIONS

Michael Bailey
Babcock-Wilcox Fellow

David Anderson
Assistant Professor
of Mechanical Engineering

Computer Aided Design and Graphics Laboratory

Dennis Strader
Graduate Research Assistant

Werner Soedel
Professor of
Mechanical Engineering

Ray W. Herrick Laboratory

School of Mechanical Engineering
Purdue University
West Lafayette, Indiana

Introduction

Computer analysis in engineering design has become a fact of life. However, it is always a problem to present the results of such an analysis in a way that is meaningful to the user. This paper deals with one effective approach to that challenge.

A compressor analysis program developed at the Ray W. Herrick Laboratories at Purdue required two minutes to run on the University's CDC 6500 and produced a printed output that was nearly an inch thick. This output consisted of columns of numbers and several line-printer graphs.

The problem was to design a set of procedures that would enable the compressor designer to view the results of his program without having to leaf through pages of printout.

Computer Graphics

In conjunction with the Mechanical Engineering Department's Computer Aided Design and Graphics Laboratory, it was decided that the CDC 6500 would handle the extensive calculations and then pass the output data to a computer graphics program for display. Thus, it was to be a two-step interactive process. At the same time, it was also decided that the graphics display would include a moving piston-cylinder configuration and a dynamic Pressure-Volume diagram.

Hardware and Software Configuration

Figure 1 shows the equipment configuration used in this project. Figure 2 shows the IMLAC Computer Graphics Terminal.

The display program, written in Fortran, operates under the Design Lab's GRAFIC system (1), a versatile and highly interactive system that communicates between the PDP 11/40 and the IMLAC PDS-1. Under this system, the IMLAC accepts plotting commands from Fortran-callable subroutines in the PDP 11/40. It builds a list of all commands sent and uses this list to refresh the screen display forty times per second without requiring any attention from the user.

GRAFIC's interactive capabilities are reflected in the user input devices which include a "Mouse," Joystick, and Digitizing Pen. In addition, the user can supply program control information and numerical input through a Five-finger Keyset and the IMLAC keyboard. The addition of this type of user interaction to computer graphics heightens GRAFIC's utility to Computer Aided Design.

Implementation

The existing compressor analysis program was modified to complete calculations for one whole compressor cycle before beginning to write on the output file. This was done to insure steady state.

For every 2.3 degrees of crank angle

the program output:

(1) Crank angle
(2) Displacements for the suction valve sections
(3) Displacements for the discharge valve sections
(4) Cylinder pressure
(5) Cylinder volume
(6) Piston displacement

This data file was passed to the PDP 11/40 program and placed in arrays. Plotting commands were sent to the IMLAC to draw the background which consisted of the static cylinder and the P-V outline. By looping through the data arrays, commands were sent to the IMLAC to move the piston, re-draw the valves in their new positions, check cylinder pressure and draw oriented flow arrows when required, and drive the small square around the P-V outline.

From the IMLAC keyboard, the user can slow down or speed up the display or temporarily hold the display in its current position for longer observation.

Development of the Computer Simulation Model

The mathematical formulation of the computer simulation model used in the movie was developed for a short course offered at Purdue University in 1972. The text "Introduction to Computer Simulation of Positive Type Compressors" by W. Soedel [2] presented a mathematical model of compressors along with the Runge-Kutta technique of solving ordinary differential equations. However, people who had taken this short course felt it would be helpful to have a computer program example of this model. With this in mind a text "Anatomy of a Compressor Simulation Program" was developed by W. Soedel and S. Wolverton [3] for a 1974 short course "Applications of Computer Simulation to Positive Displacement Type Compressors". The results of the simulation program show lists of parameters as a function of crank angle. The use of a plotting routine with this program enables the user to see an overall view of how one quantity varies in relation to another quantity. Even with this type of output, the designer would normally have a hard time visualizing the effects of more than a couple output parameters at once.

A Computer Graphic Representation of the Simulation Model

Computer graphics enables one to see how several output quantities vary at the same time, in addition to the typical simulation output. The computer graphics model used in the film presented as part of this paper is based on the example program presented at the 1974 short course. The compressor that was modelled was a reciprocating piston compressor whose valve reeds are of a circular ring configuration. The two reeds are attached to a common base with the suction reed being mounted on the bottom side and the smaller discharge reed being mounted on the top side as can be seen in figures 3a thru 3g and 4a thru 4g.

To describe the film for those who have not seen it, representative pictures of the computer graphics screen were taken. Figures 3a thru 3g and 4a thru 4g are sequential photographs of the computer graphics simulation model. Features to note of figures 3a thru 3g and 4a thru 4g are

- the crank rotates clockwise
- the arrows indicate the direction of flow through the ports
- A "box" traces out the pressure-volume (P-V) diagram on the right hand side of the screen
- on the pressure volume diagram PD and PS denote the discharge plenum and suction plenum pressures, respectively. These pressures were taken to be constant.

Following the picture sequence as shown by the photographs, we are able to see the following stages

3a: The piston is compressing the gas, but looking at the P-V diagram it can be seen that the cylinder pressure is less than the discharge plenum pressure (PD) thus the discharge valve is still closed.

3b: At this point the cylinder pressure is higher than PD causing the discharge valve to start to open. The "flow arrows" indicate that gas is leaving the cylinder.

3c: Here the discharge valve is still opening.

3d: Maximum displacement occurs here. This is represented by the first peak in figure 5, which is a still picture appearing in the movie, showing discharge valve displacement versus crank angle.

3e: This is the first closing of the discharge valve. This is the low spot between the first two peaks on figure 5.

3f: This is during the third opening of the discharge valve. At this time, the valve is open, but the cylinder pressure has dropped below PD resulting in gas flowing back into the cylinder. This condition is referred to as backflow which can be seen by the "flow arrows" indicating flow into the cylinder.

3g: This is a later shot of back flow through the discharge valve.

4a: Here the cylinder pressure is dropping as the suction process begins. At this time the cylinder pressure is above the suction plenum pressure, therefore there is no flow through the suction valve.

4b: As can be seen on the P-V diagram the cylinder pressure is below PS, thus there is flow through the suction valve.

4c: This is the maximum displacement of the suction valve for the first opening. This condition correspands to the first peak on figure 6. Figure 6 is a still picture of the suction valve displacement as a function of crank angle.

4d: Here the suction valve is starting to close.

4e: At this time the suction valve is almost completely closed.

4f: This condition happens near the maximum displacement of the suction valve. This corresponds to the second peak of figure 6.

4g: At this time the cylinder pressure became higher than the discharge pressure, while the suction valve was slightly open. The result is slight backflow.

Closure

The purpose of this paper and the associated movie presentation was to illustrate the usefulness of computer graphics for visualizing compressor simulation output. As computer programs become more and more complex, it becomes more and more difficult to present the results of such programs in a meaningful way to the designer. This technique offers a way to do this.

References

1. Anderson, D.C. and Belleville, R.L.; "Two Approaches to On-line Graphics System," to be published in Computers and Graphics, Pergamon Press, 1976.

2. Soedel, W., "Introduction to Computer Simulation of Positive Displacement Type Compressors", Short Course Notes, Ray W. Herrick Laboratories, Purdue University, 1972.

3. Soedel, W. and Wolverton, S., "Anatomy of a Compressor Simulation Program," Short Course Notes, Ray W. Herrick Laboratories, Purdue University, 1974.

FIGURE 1

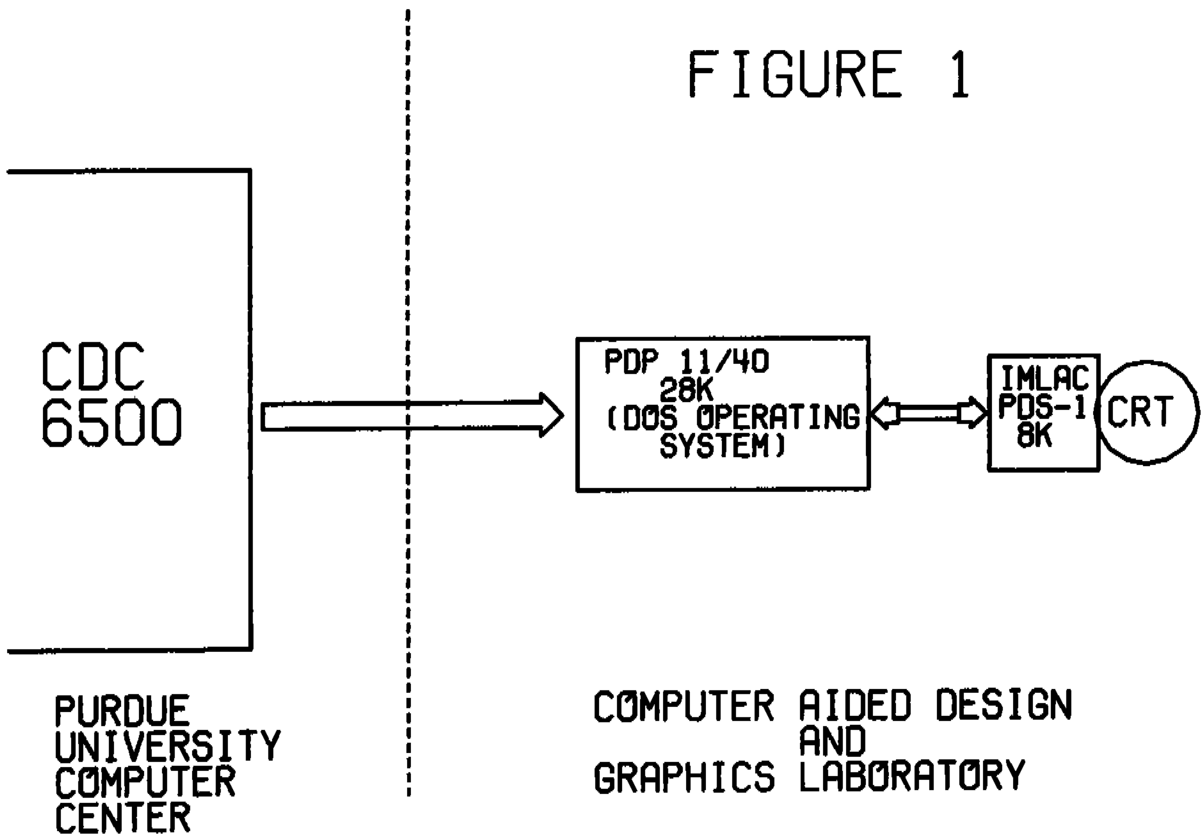
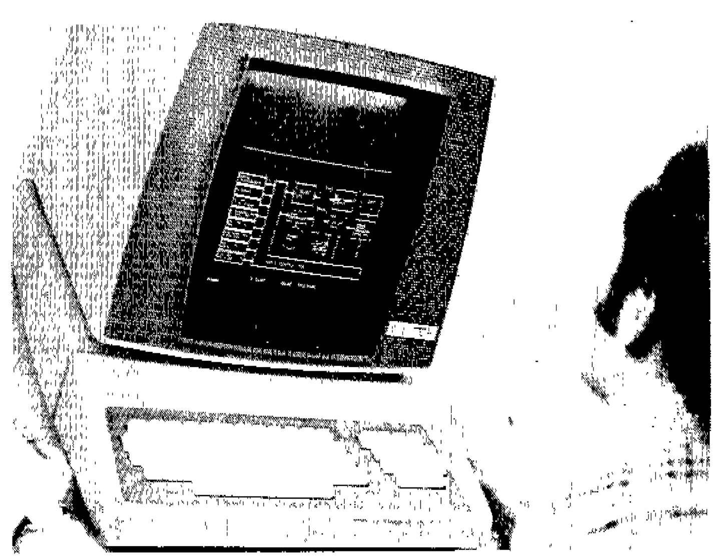
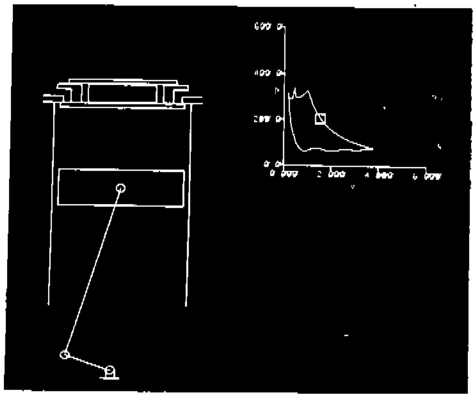


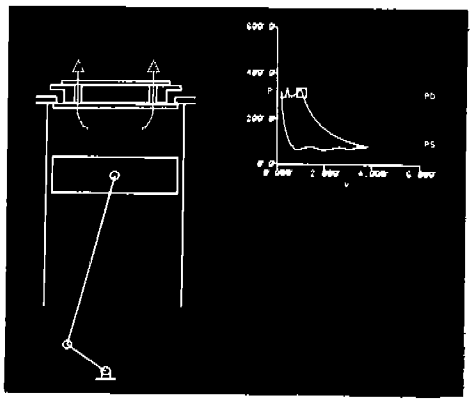
FIGURE 2



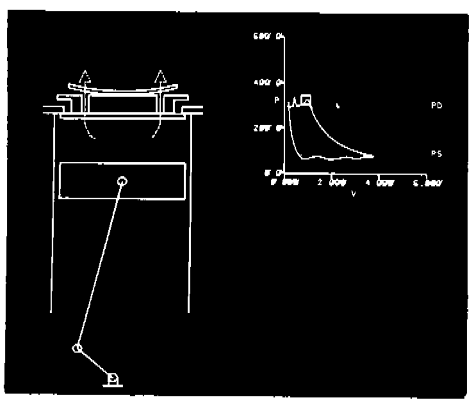
A)



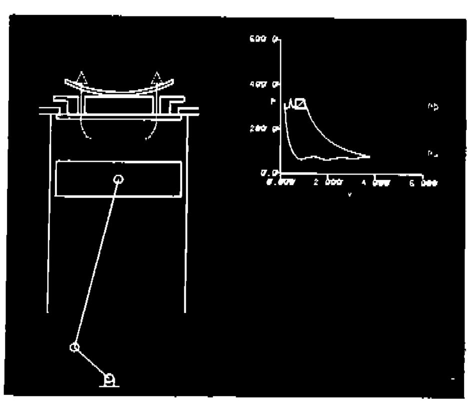
B)



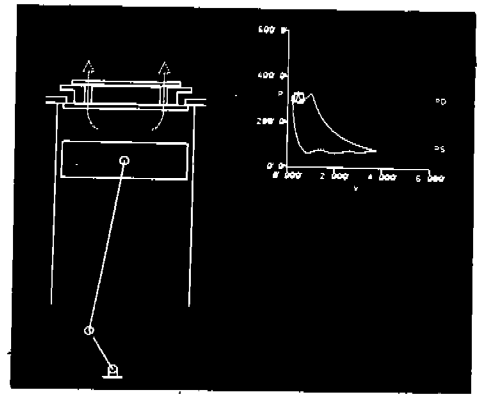
C)



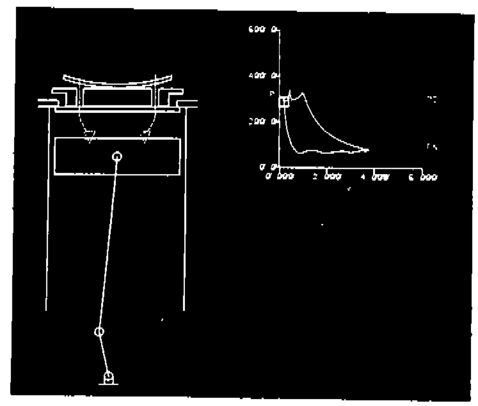
D)



E)



F)



G)

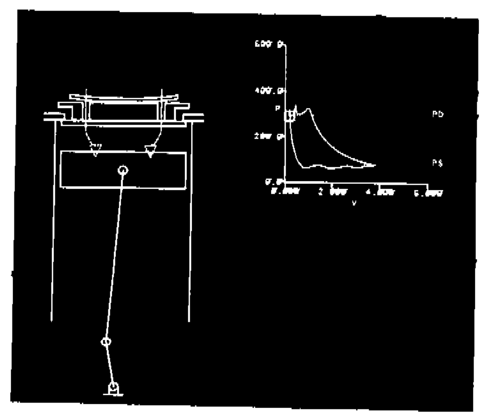
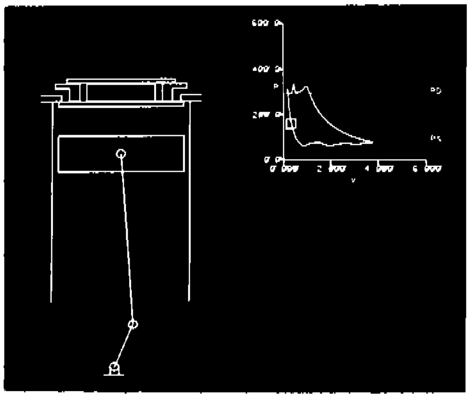
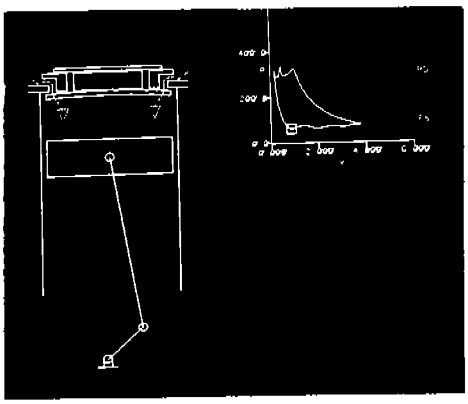


FIGURE 3
DISCHARGE CONDITIONS

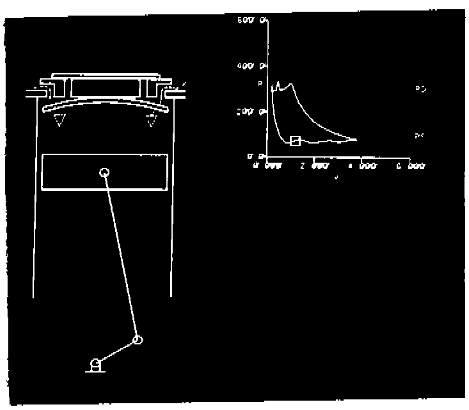
A)



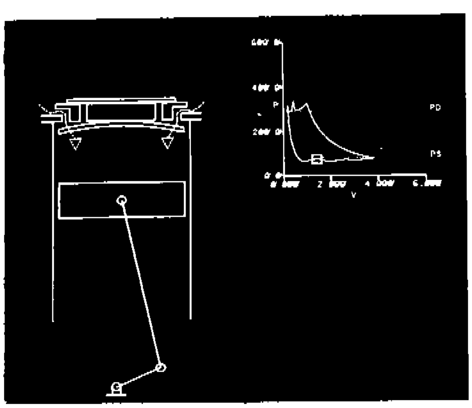
B)



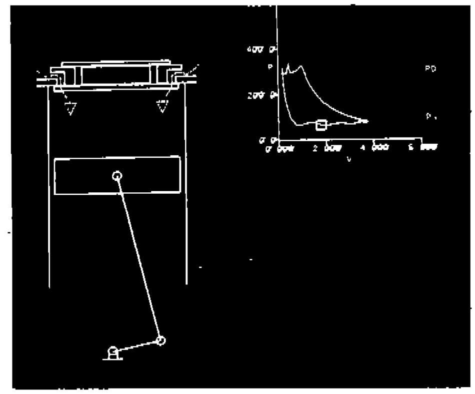
C)



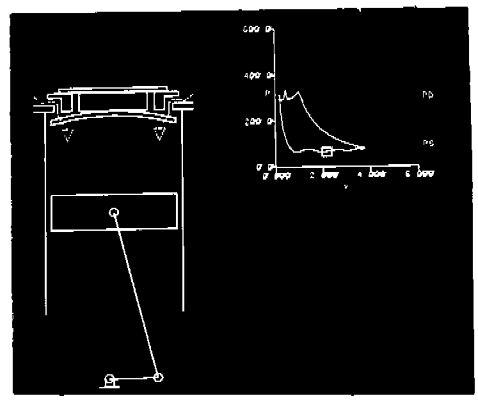
D)



E)



F)



G)

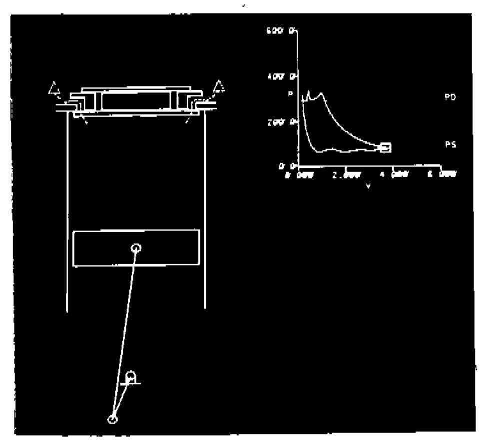


FIGURE 4
SUCTION CONDITIONS

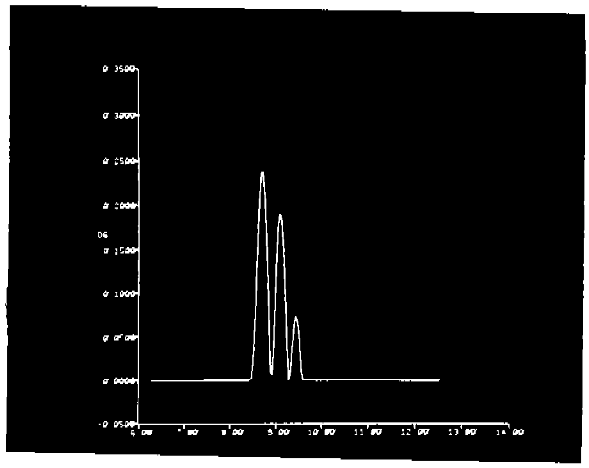


FIGURE 5
DISCHARGE VALVE DISPLACEMENT
VERSUS CRANK ANGLE

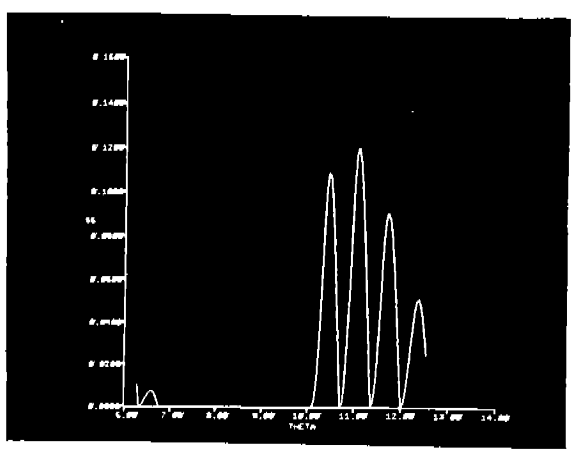


FIGURE 6
SUCTION VALVE DISPLACEMENT
VERSUS CRANK ANGLE